Internal Structure of Sensors

When designing sensor systems, there are usually two choices: designing and manufacturing the internal circuits of the sensors yourself or using existing sensor modules. I am particularly concerned with two types of applications: environmental monitoring and medical devices. Correspondingly, there are two different types of sensors. For environmental monitoring, we want to use temperature and humidity sensors.

Principles of Temperature and Humidity Sensor Design:

- Temperature: The most important component is the thermistor.
- Humidity: The most important component is the capacitive humidity sensor.

Temperature and Humidity Sensors: DHT11 / DHT22 Thermistor

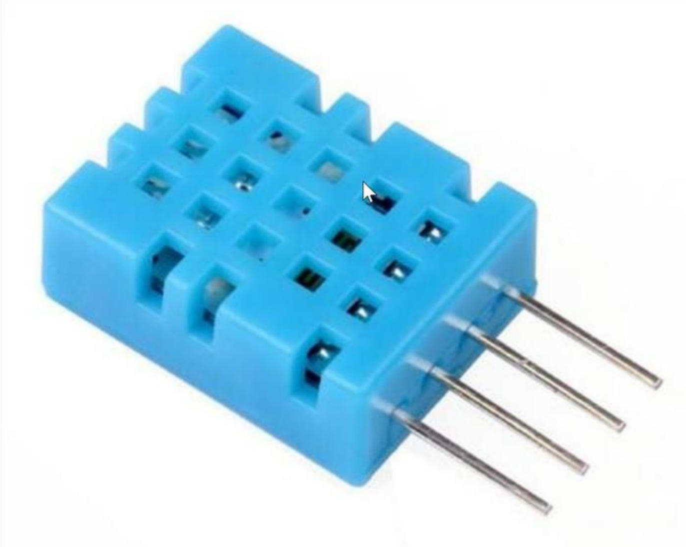
Circuit Design Perspective:

Temperature Sensor: The thermistor is connected to a voltage divider circuit.

Humidity Sensor: The capacitive sensor is usually connected to an RC oscillator circuit.

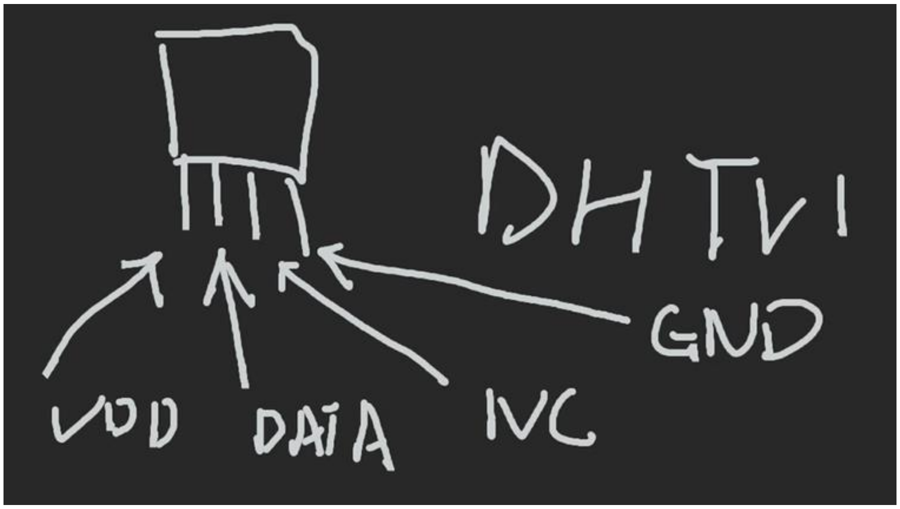
Excessive sensitivity can lead to inaccurate measurements. High sensitivity can be affected by noise or signals, allowing unrelated external noise to interfere and affect measurement accuracy. Sensors should have a high signal-to-noise ratio (SNR).

DHT11 Temperature and Humidity Sensor:



DHT11 is a common temperature and humidity sensor, while DHT22 is a more flexible and advanced version.

Pin Configuration:



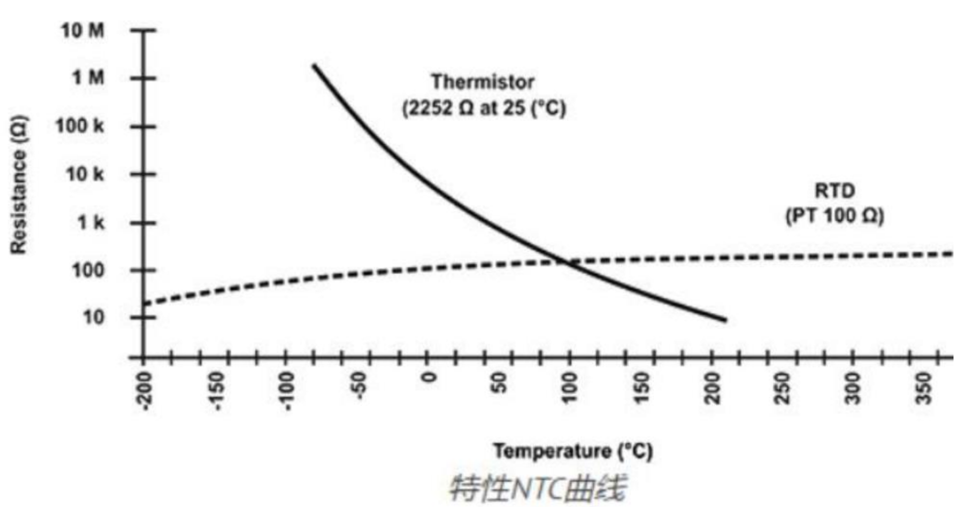
VDD: Voltage

DATA: Transmits data. After measuring temperature and humidity, it transmits the data to a microcontroller like Arduino through this pin.

NC: No connection, no special meaning

GND: Ground

Thermistor: A special type of resistor whose resistance varies with temperature. The DHT11 uses a negative temperature coefficient (NTC) thermistor to measure temperature. As temperature changes, the resistance of the thermistor changes.



A thermistor's resistance decreases with an increase in temperature. This characteristic makes NTC thermistors suitable for temperature measurement. Unlike regular resistors that have a constant resistance, the thermistor's resistance changes based on its temperature.

Relationship Between Resistance and Temperature:

The NTC thermistor's resistance value and temperature relationship is usually obtained through the Steinhart-Hart equation or look-up tables.

Equation: $T = A + B*\ln(R) + C*(\ln(R))^3$

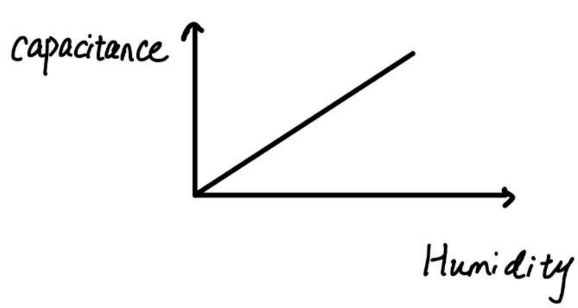
where T is the temperature in Kelvin, R is the resistance value, A, B, and C are specific constants of the material.

Materials of NTC Thermistors: NTC thermistors are typically made from metal oxides such as nickel, cobalt, and manganese due to their temperature sensitivity.

NTC thermistors provide highly accurate temperature measurements, especially within a specific temperature range. Their small size and high thermal conductivity allow them to respond quickly to temperature changes.

Humidity Measurement:

The principle is like temperature measurement but involves measuring capacitance. **The relationship is directly proportional.** The change in capacitance is continuously monitored and converted into humidity data. The final output signal involves analog-to-digital conversion.



The DHT11 has a dielectric material sensitive to humidity. **As the humidity changes, the dielectric constant changes, leading to a change in capacitance.** This change is then detected and converted into a humidity measurement.

Medical Sensor - MAX30102

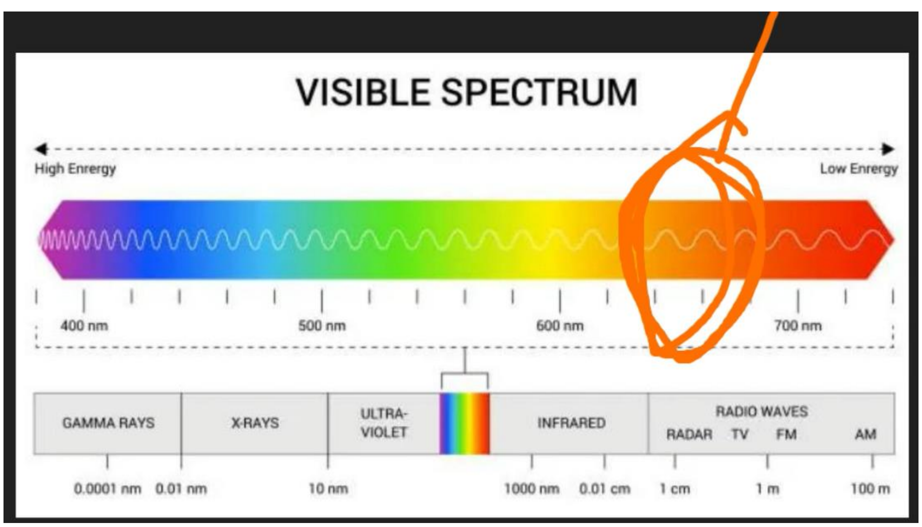
Focus on medical sensors such as the MAX30102, used for heart rate and blood oxygen saturation measurements.

Internal Structure of MAX30102:

Optical Section: The MAX30102 contains a red and infrared light emitter with two LEDs: **one emits red light at 660 nm, and the other emits infrared light at 880 nm.** These light sources alternately emit light, and **by measuring the light reflected from the skin, the sensor can calculate blood oxygen saturation and heart rate.**

A photodetector is used to detect the intensity of the reflected light. This highly sensitive light receiver can detect changes in different wavelengths of light, which reflect the oxygen content in the blood and the rhythm of the heartbeat.

Optical Principle: By measuring the reflected light, the sensor can calculate the ratio of oxygenated to deoxygenated hemoglobin in the blood. The emitted light has different wavelengths: one at 660 nm and the other at 880 nm.



Biological Knowledge:

Blood oxygen saturation refers to the proportion of oxygen bound to red blood cells in the blood. Hemoglobin, a protein in our blood, is responsible for carrying oxygen. When hemoglobin binds with oxygen, it turns bright red; when it does not, it remains darker.

Red Light (660 nm): Oxygenated hemoglobin (HbO_2) absorbs less red light and more infrared light. Infrared Light (880 nm): Deoxygenated hemoglobin (Hb) absorbs more red light and less infrared light.

The MAX30102 alternately emits red and infrared light. By measuring the intensity of the light reflected from the skin, the sensor can calculate the ratio of oxygenated to deoxygenated hemoglobin in the blood, thereby determining blood oxygen saturation.

Heart Rate Measurement:

Each heartbeat causes a periodic change in the intensity of the reflected light. This change corresponds to the rhythm of the heartbeat. The photodetector captures these periodic changes in light intensity. By analyzing these changes, the heart rate (beats per minute) can be calculated. Despite its small size and simple principles, the MAX30102 sensor is very useful. By detecting and receiving light, it can measure vital signs. For example, smartwatches often measure vital signs using similar sensors.

Internal Structure of the MAX30102:

- Optical Part: Emitters and photodetectors
- Analog Part: Amplifiers and ADC (Analog-to-Digital Converter)
- Digital Part: DSP (Digital Signal Processor) & I2C Interface

Amplification: The signals received from the photodetector are amplified for further processing. Since heart rate and blood oxygen signals are usually weak, a low-noise amplifier is used to enhance the signal strength. The ADC converts the analog signals into digital form.

Digital Processing: The MAX30102 has a built-in digital signal processor that processes the digital signals from the ADC. It filters out noise and extracts useful heart rate and blood oxygen data.

I2C Interface: This communication interface transmits the processed data to the main control device.